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# ARGOS Decision Support System for Emergency Management

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**Abstract.** The ARGOS decision support system is used for consequence assessment and decision support following a nuclear, radiological or chemical emergency. This paper will focus on the radiological domain. The ARGOS system is in operation or being commissioned in 8 European countries, as well as in Canada, Brazil and Australia. Since the initial version was released 15 years ago, the system has developed from a simple data presentation application to a sophisticated platform which integrates radiological monitoring data, atmospheric dispersion models and calculation of doses in the food chain and the urban environment.

**KEYWORDS:** *Radiological Decision Support System, Atmospheric Dispersion, Monitoring, Food Dose Modelling and Countermeasures*

## 1. Introduction

The development of ARGOS NT (Accident Reporting and Guiding Operational System) was started in 1993 and implemented as a graphical Windows NT application with data stored in a SQL database. Prolog Development Center A/S (PDC) developed the programs in cooperation with the Danish Emergency Management Agency (DEMA.)

In the late 1990s DEMA was involved in a large Danish nuclear safety programme with the Baltic countries and Poland. As part of this programme ARGOS was developed further with the EU providing a substantial contribution under the EC sixth and seventh Framework research programmes, to the models used by ARGOS.

In 2001 more countries implemented ARGOS and the ARGOS Consortium was established between the user countries and PDC. Among the users of ARGOS an informal but very efficient network has evolved and has significantly improved the cooperation between the National Emergency Organisations. A series of major steps in the conversion of ARGOS from a Radiological to a full chemical and biological capabilities system will be completed in 2008.

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## 2 Monitoring

ARGOS is highly integrated with monitoring data. Especially data from the Airborne Gamma Monitoring (AGS) system are well integrated in ARGOS. The delay from when AGS-data is extracted from an aircraft until this data can be used for food dose modelling in ARGOS can be as short as 1h. Advanced software for this data handling and analysing is part of the ARGOS consortium agreement. From the initial design, the ARGOS system is integrated closely with an SQL server. In fact, from its first version ARGOS supported GIS presentation of Monitoring Data stored in the SQL database. In most ARGOS installations monitoring data from automatic systems are displayed, and alarms and warnings are issued from the ARGOS system.

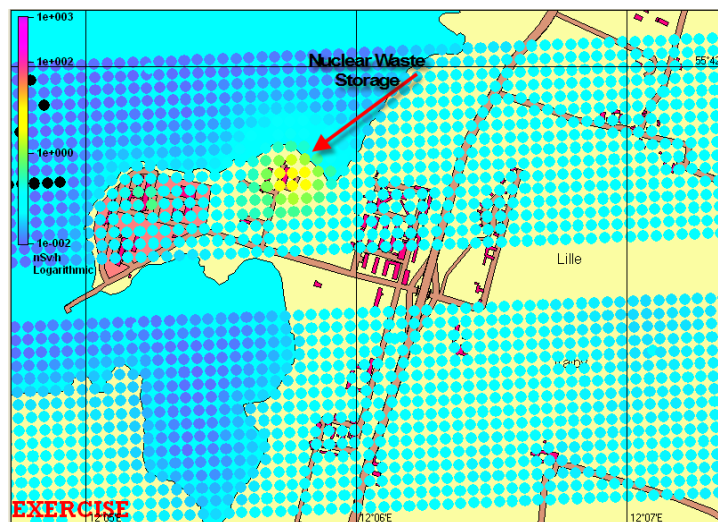


Figure 1 Airborne Gamma Measurements

Monitoring data from other countries delivered in the EURDEP format are continually imported into the system database by automatic services. Export of gamma station monitoring data and data from local met towers is also done automatically by ARGOS Windows Services. Moreover, ARGOS provides functionality for interactively both importing and exporting data in the EURDEP format. Data entered manually by monitoring field teams are used by the system's dose monitor for online surveillance of personnel.

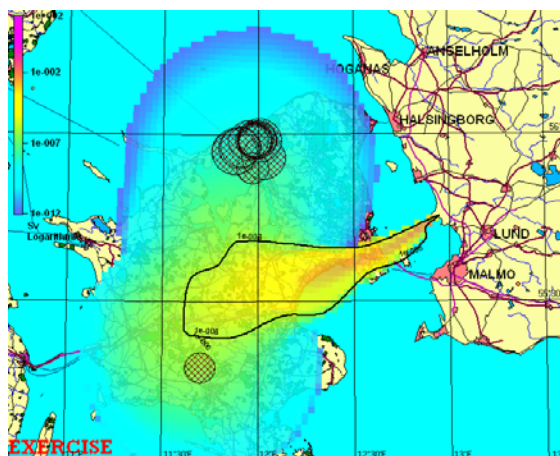
The PMS online monitoring system is displayed with status icons linked to a more detailed display.

## 3 Atmospheric dispersion

Atmospheric dispersion in ARGOS is divided in three parts, a short and mesoscale dispersion model LSMC /RIMPUFF, the urban dispersion model URD and long-range models: DERMA (Danish), MLDP0 (Canada), SNAP (Norway) and MATCH (Sweden).

### 3.1 The short range model

RIMPUFF/LSMC comprises a meteorological pre-processor, which calculates time and height dependent fields of meteorological parameters (deposition, stability, 3D wind etc.) based on the data provided by the National Numerical Meteorological Weather prediction models, by meteorological masts or by a combination of these. Wet deposition is calculated from Doppler radar data when these become available and this provides a very high resolution wet deposition calculation.



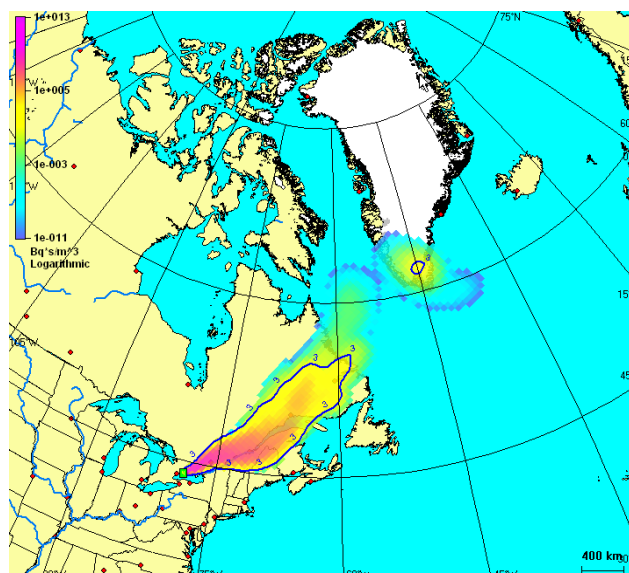
*Figure 2 Local Scale dispersion: Inhalation dose*

By using Long Range Dispersion parameters RIMPUFF may be used up to many hundred kilometres from the source.

The calculated gamma doses, concentrations and depositions produced by RIMPUFF can be used as input data for the Food Dose Module, FDM/AgriCP and the urban dose model ERMIN. RIMPUFF has been validated successfully through several experiments.

### **3.2 Long range dispersion models**

These models are not part of ARGOS but are executed by the National Meteorological Institutes. The inputs into the long range models are automatically uploaded from ARGOS to the Meteorological centres where the meteorological data are taken from the operational models' numerical weather prediction models (NWP). At the Meteorological Institute up to 3 calculations are executed on different versions of the NWP model, with various geographical coverage and resolution. When the calculations are finalised, the monitor function in ARGOS will prompt the users for downloads of the results. The long range dispersion calculation can be linked to the Food Dose and URBAN dispersion modules!



*Figure 3 Long Range dispersion result from DERMA – simulated release with DERMA*

Currently ARGOS has support for Long Range Dispersion Models operated by national Met services in Denmark (DERMA-model), Canada (MLDP0-model), Norway (SNAP-model) and Sweden (MATCH-model).

Also as part of the interface to long range models an interface has been implemented for a Swedish Nuclear Detonation model.

### **3.3 Trajectory Models**

Trajectories can be calculated locally by RIMPUFF or remotely at the meteorological services where the models are accessed and controlled by ARGOS.

### **3.4 Urban Dispersion**

This new implement was necessitated since it became clear that larger scale dispersion codes like RIMPUFF are not always suited for the estimation of contaminant dispersion following an in-town low-altitude release, as it could be expected from for instance a 'dirty bomb' blast. In RIMPUFF, inhabited areas are simply modelled as areas with enhanced surface roughness and different deposition rates as compared to open areas. This is adequate for releases for which the major part passes over towns, e.g. a release from an accident at a nuclear power plant. At low altitudes in towns, the wind field and the spectrum of turbulence are highly affected by the presence of buildings and other obstacles and by the way they are arranged, so the plume shape and dispersion pattern near the point of an in-town low-altitude release is therefore to a high degree determined by the buildings and street canyons. In the Urban Dispersion model URD the presence of buildings influences the dispersion in different ways: it limits the size of the large scale horizontal eddies otherwise present in the atmosphere to something in the order of the average street canyon width and thereby limits normal atmospheric dispersion, while it enhances the dispersion by widening the plume to the edge of interfering buildings. It also delays part of the plume by retaining it in stationary recirculation zones on the downstream side of the buildings from where it is then again relatively slowly released. The effect of this is most pronounced at a wind shift.

## **4 Source modelling in ARGOS**

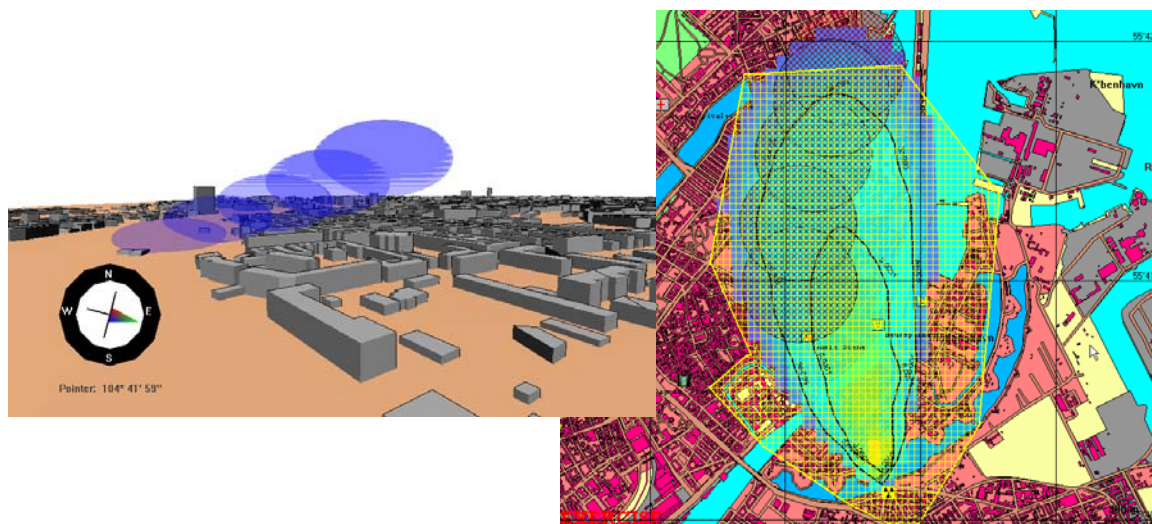
ARGOS can combine releases from several sources to one single calculation, e.g., releases from several locations on a reactor site (buildings, heights) or radiological releases combined with dirty bombs.

### **4.1 Reactors**

Information on all power reactors from the IAEA database is stored in the database and the shutdown inventory can quickly be estimated, also source term WASH 1400 or more recent estimates of sources is part of the ARGOS system that includes a complete build-up tool. The reactor site definitions in ARGOS include link to meteorological towers that can be used by RIMPUFF without further setup.

### **4.2 Dirty Bombs**

ARGOS development is ongoing to enable decision support in connection with 'dirty bomb' scenarios and this development is supported by members of the ARGOS Consortium. So far, deposition data libraries have been developed to extend the ERMIN concept to cover the particle size range from approx. 0.5  $\mu\text{m}$  (corresponding to condensation particles formed after high pressure phase transition of contaminants in an explosion) to a few tenths of microns, which is deemed to be the largest particles that could be relevant to atmospheric dispersion, considering the likely effective release height range. The initial plume rise and dimension parameters have been described as a function of the TNT equivalent explosive mass, on the basis of several independent data sets from explosive tests. Also the relationship between indoor and outdoor contaminant air concentrations has been described for different particle sizes and plausible building canopy filter effects, ventilation rates and indoor deposition rates.



*Figure 4 Dirty bomb simulations with risk area and 3D visualization*

It is evident from recent experimentation (Harper et al., 2007) that the aerosolisation process in connection with a 'dirty bomb' explosion is strongly dependent on the initial physicochemical characteristics of the contaminating material, as well as the geometrical construction of the device. For instance, if the source is a metal ( $^{60}\text{Co}$  and  $^{192}\text{Ir}$  would here be among the primary radio nuclides of concern), practically all the contamination would be dispersed as large fragments, and atmospherically dispersible particles would only occur if sufficient pressure is generated to create phase transition. Contrary to this, if the source were initially in ceramic form (e.g., a  $^{90}\text{Sr}$  source from an old Soviet RTG), no phase transition would occur according to Harper et al. (2007), and a particle size spectrum with much of the mass associated with large, insoluble, but still widely dispersible, particles would be expected. These particles would not only deposit very differently on the different surfaces; they would also behave differently in the environment after the deposition has occurred. This is at the extreme illustrated by the very high decontamination factor of 50, obtained by Clark and Cobbin (1964), when hosing water on a street contaminated by insoluble 44-100  $\mu\text{m}$  particles. If the contamination had instead been in the form of submicronaceous soluble Cs particles, as seen after the Chernobyl accident, hosing at the same pressure would be expected to only remove about half of the contamination. This means that parameters describing both the natural and forced contaminant removal/migration processes in the inhabited environment need to be specified for the relevant particle characteristics. In ARGOS, the 'dirty bomb' scenario is implemented as datasets in the atabase and is not directly calculated by the system.

## **5 Food Dose Modelling**

ARGOS includes the FDMT model for modelling of the food chain transfer and resulting doses, the simulation model for agricultural countermeasures AgriCP and also interfaces to the STRATEGY food chain countermeasure model.

### **5.1 FDMT.**

FDMT is based on the radioecological model ECOSYS. The model also includes doses from deposited activity and resuspension and so can also be considered as a general dose screening model. The food chain module estimates the dry and wet deposition onto a variety of crops from the time integrated activity concentration in air, the wet deposited activity per unit area and the amount of rainfall connected with the wet deposition. These data can be measured in principle, but in many cases other data are available from measurements, e.g. total deposition, activity concentration in grass.



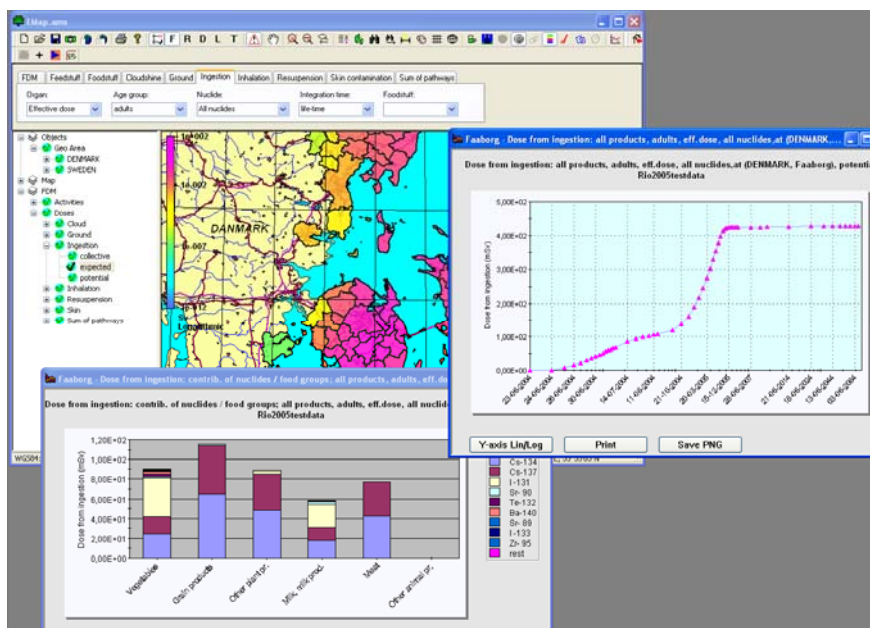


Figure 5 Food Dose Modelling

To make best use of such measurements, the new module makes an estimation of activity in air, wet deposition and amount of rainfall at a certain location based on the available set of measured data. Since such estimations are not straightforward in many cases, certain assumptions have to be made which, of course, increase the uncertainty of the resulting predictions of food contamination and doses. Nevertheless, they allow estimating at least an upper limit of these radiological quantities.

## 5.2 AgriCP.

AgriCP (**A**gricultural **C**ountermeasure **P**rogram) bases on the food and dose model FDMT and is designed to estimate the effects of all kinds of agricultural countermeasures directly when simulating the transfer of radionuclides through the food chain. For this purpose the model uses the same functions as FDMT but modifies the set of model parameters used in these functions according to the simulated countermeasure. This approach allows for correct modelling of all reasonable single agricultural countermeasures and even combinations of countermeasures.

Data and information required for all feasible countermeasure options have recently been compiled for food production systems in agricultural and semi-natural areas within the framework of the European research project EURANOS. This compendium covers all phases not only of nuclear, but also of radiological accidents (e.g. terrorist attacks). To assist decision-makers in their choice of options for addressing future nuclear and radiological incidents, additionally a handbook for use in Europe has been developed. It provides guidance on how to extract a subset of countermeasures and waste disposal options most applicable within a region. AgriCP is designed in such a way that it can consider the input on agricultural countermeasures from the compendium and handbook.

Implementing countermeasure options directly into the food chain calculations seems to be the optimum solution to achieve flexibility and consistency. To this purpose, a database had to be developed which converts the effectiveness factors for particular countermeasures (from the EURANOS compendium) into e.g. modified parameters for particular transfer rates such as the transfer soil – crop or the transfer from the cow to the milk in the gut.

With this approach feedback of an agricultural countermeasure on the estimation of the radiological situation can be realised (e.g. increasing contamination of feed- and foodstuffs through disposal of contaminated products like milk in agricultural areas). This requires a re-calculation of the activity

contamination once the countermeasure is selected. By implementing such an option into AgriCP, the assessment of waste options becomes possible for some foods.

The following list shows the basic agricultural countermeasures currently considered in AgriCP:

- Food disposal or stopping production
- Food processing
- Storing food
- Removing animals from contaminated feed
- Supplementing animals feed with clean feed
- Substituting of animals feed with other contaminated feeds
- Addition of sorbents/Boli
- Amelioration
- Change in land use
- Change of crop species or variety
- Deep ploughing
- Skim and burial ploughing
- Top soil removal (small scale only)

Endpoint of the calculation are e.g.:

- Activity in food before and after the application of the measure
- Area where intervention criteria are exceeded
- Duration of contamination exceeding the intervention criteria
- Amount of food exceeding the intervention criteria
- Projected, residual, averted collective dose
- Projected, residual, averted max. individual dose
- Dose to workers
- Resources (e.g. amount of uncontaminated food required)
- Map indicating which radionuclide groups exceed the intervention criteria

### 5.3 STRATEGY

STRATEGY is an acronym for **Sustainable Restoration and Long-Term Management of Contaminated Rural, Urban and Industrial Ecosystems**. It is based on the SAVE model which spatially predicts contamination of the food chain with Cs, Sr, Pu and Am. The STRATEGY model offers extensive consideration of possible countermeasures to reduce dose. The model is only implemented in Norway.

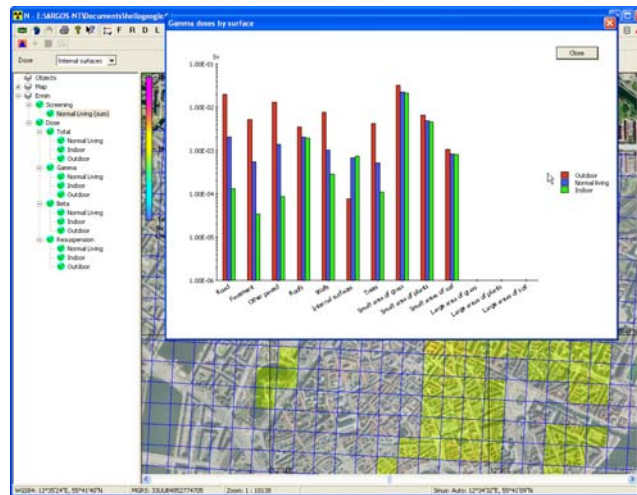
“STRATEGY aims to develop and assess new methods whereby individual countermeasures can be combined within a robust, realistic, cost effective and socially acceptable restoration strategy. This will significantly advance the Member States abilities to manage areas contaminated by any future nuclear incident in a sustainable manner. The project is focused on radio nuclides with long physical half-lives, specifically  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$  and actinide elements.”

### 6 ERMIN (EuRopean Model for INhabited areas).

After an accident, emergency management must continually evaluate which remediating actions are needed where in specific areas, which countermeasures should be kept in place, and which should be lifted.

For this purpose projected doses must be calculated. Consequences of implementing different countermeasures are then evaluated based on saved doses, waste and worker dose as well as practical issues and cost. The doses cannot be derived from simple measurements at any time. The future behaviour of the deposition and its interaction with material (surfaces etc) must be modelled represented with a detailed model for inhabited areas.





*Figure 6 ERMIN calculation on 100 m grid overlaid on Google Maps, The graph shows dose contributions from different urban surfaces; useful information to assist with targeting countermeasures appropriately*

The European Model for Inhabited Areas (ERMIN v1) was developed under EURANOS, an integrated project of the EC Sixth Framework Programme. It is both a model and a software tool. As a model it simulates the behaviour of radio nuclides in the inhabited environment and calculates the exposure of the population as well as other relevant endpoints. As a tool it allows a user to explore different recovery options following the contamination of an urban environment with radioactive material and to refine a strategy. It has been designed to be implemented within the RODOS and ARGOS Nuclear Emergency Decision Support Systems (DSS) or as a standalone application.

Input data required by the model includes a description of the environment, initial deposition of radio nuclides on to a reference surface and a description of countermeasures. ERMIN v1 can accept deposition from RIMPUFF and surface measurements and the Inhabited Area Measurement Module (IAMM) – a data assimilation module also developed under EURANOS, Countermeasures include decontamination, fixing material to a surface, shielding and relocation.

The ERMIN implementation in ARGOS includes an interactive user interface for describing the urban environment as varying proportions of idealised environments if not already in the database.

## **7 Countermeasure and Multi attribute decision support module.**

A fast dose calculation on all pathways can be made based on airborne measurements of deposition or atmospheric dispersion calculation. Doses are calculated and assigned to administrative units like municipalities. This module enables a fast scanning of expected concentration of radio nuclides in foodstuff can be compared with existing standards. Based on the calculations different portfolios of countermeasures can be compared on: dose saved, cost, worker dose and waste. The results of these calculations can then be exported to the standard Multi Attribute Decision Support Tools like VISA:

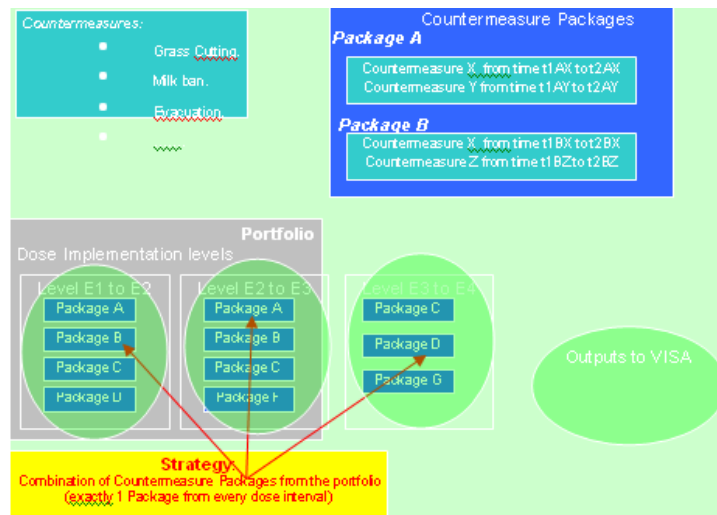


Figure 7 Countermeasure concept in ARGOS

## 8 Communication

ARGOS is designed to communicate with other DSS systems with direct exchange of source term data like the American IXP initiative hosted by Lawrence Livermore laboratory.

Results from ARGOS can be directly published on the Internet manually or automatically in form of animations or screen dumps; also an Auto Prognosis Internet Service is part of ARGOS with forecast for a number of reactor sites for every x hours.

First responders can order simple prognosis for Chemical releases on a web server. ARGOS also provides support for subsets of the ATP-45 NATO standard.

## 9 GIS support in ARGOS

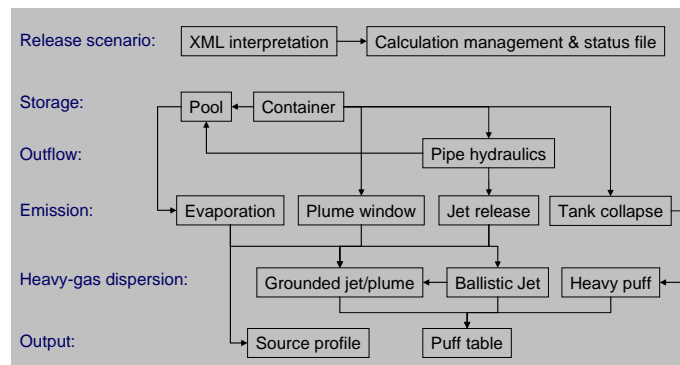
ARGOS was originally developed with a native map module that can handle standard inputs from shape- and GeoTIFF files. But the new release can also use mapping layers from Google Map and WMS servers.

ARGOS can flexibly map the links and relationships between various spatial datasets, e.g., contaminated area, population grid or disrupted infrastructures (See also figure 5 where affected hospitals and other vital infrastructure etc is marked on the map)

## 10 ARGOS support for Chemical Releases

The first version of ARGOS analysing chemical releases was released in ARGOS 8.0. The new ARGOS Chemical extension includes a source model and a chemical database, as well as interface to the URD model linked to RIMPUFF.

The source model includes gaseous, liquid, or two-phase outflow; evaporation from a boiling or volatile pool; and heavy-gas dispersion from continuous and instantaneous sources. The metrological pre-processor in ARGOS are also supplying the Chemical Source model with actual data like temperature and pressure.



*Figure 8 Source Model*

## 11 ARGOS support for Biological Releases

The B extension includes a biological database and an interface to run RIMPUFF.

## 12 The Near Future of ARGOS

The near future for ARGOS Nuclear Radiological use will be focused on improved utilisation of the existing models and improved support for the general emergency management.

## 13 Acknowledgements

Work on some of the ARGOS modules including AgriCP and ERMIN received partial financial support from the European Commission Sixth Framework Programme (Nuclear Fission/Radiation Protection) under the EURANOS integrated project: European approach to nuclear and radiological emergency management and rehabilitation strategies (Contract No: FI6R-CT-2004-508843).

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